

3D image acquisition and reconstruction explained with online animations

PRESENTED BY ADAM KESNER, PHD, DABR
UNIVERSITY OF COLORADO

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University of Colorado
Anschutz Medical Campus

Introduction

- 3D image reconstruction is
 - A fundamental aspect of clinical imaging
 - One of first aspects introduced to those interested in learning about the field
 - Physicists
 - Physicians
 - Technologist
 - Patients
 - Young students
 - Provides a great example of how math and physics support clinically useful technology

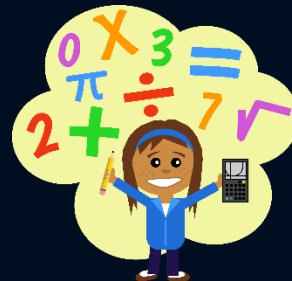
Introduction

- Fundamental principle of image reconstruction:

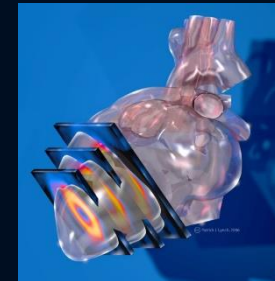
When you have 2D projection images of an object from many different angles, you can use mathematical strategies to reconstruct a 3D image of the object



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Most people comfortably understand 2D imaging

Math

3D image

- *3D imaging 1 step beyond obvious for most*
 - *Ideal starting point for introducing the field*

Introduction

- For 50+ years, image reconstruction has been taught using 2D media (textbooks, lectures, text)
- Tomographic imaging acquisition and reconstruction are sequential processes
 - Particularly lends itself to explanation with animations
- Modern computing power easily supports animations
 - gif images easy to create
 - gif images are robustly displayed with internet browsers
 - animations can be shared over the internet
 - Freely and globally accessible



Someone should
create animations for
the community

I'm someone



3D image reconstruction explained with gifs

University of Colorado Website Google: *image reconstruction animation*

http://www.ucdenv... ANALYTIC 3D R

radiology

3D image reconstruction explained with gifs

NOTE - this page contains 8 gif images (each ~ 8 Mb) - page may take several minutes to fully load. Specific loading time will depend on your internet connection speed. Once correctly loaded, gif animations should display at approximately 10 frames per second. (Alternately, you can download entire page (in a 68 Mb .zip file) outside your browser by clicking here. (right click -> save target as))

INTRODUCTION

IMAGE RECONSTRUCTION

Basic 3D image reconstruction does not need to be a complicated topic. The main principle of image reconstruction is this:

When multiple 2D projection images are acquired of an object from many angles, one can use mathematical tools to reconstruct a 3D representation of that object.

It is with this principle that one can able to acquire 3D images in medical imaging modalities: Computed Tomography (CT), Positron Emission Tomography (PET), Single Photon Emission Tomography (SPECT). There already exists an internet many useful resources for understanding image reconstruction (3Drecon, SPECT Reconstruction (Suydam, 2002), and many others).

Since this page was created by a nuclear medicine specialist, the animations were designed with respect to emission tomography (PET, SPECT), and the same can also be applied for CT.

WHY THIS PAGE WAS CREATED

As an educator in medical imaging, I believe animations can play a large role in helping students or inquisitive minds understand the principles of tomography. After searching the web, I felt this resource was lacking, and that warranted my creation of this page.

If you find this page useful, we'd love to hear it. The feedback we receive helps us justify further development of the page/site. Any comments/questions can be emailed to adam@adamquidmore.edu.

UPDATES

Page version 1.0, March 2014: Page launched.
Page version 1.1, December, 2014: gifmaker essential added (see bottom of page).
Page version 1.2, May 2015, 2016: Reorganization of slides.

DOWNLOADABLE CONTENT

Any gif image can be downloaded by simply right clicking and choosing "save as". In addition, several sets of images have been generated, and users may download these faster here: [1\) PET](#), [2\) CT](#), [3\) Phantom](#), [4\) Noise](#). All gif images will play as animations when opened with modern internet browsers.

The page can be downloaded in zip file web page format: [Analytic 3D reconstruction with gifs \(68 MB zip file\)](#)

To generate your own gifs, see bottom of page.

Users are welcome to use images for any non-commercial use.

THE IMAGING PROCESS

The main steps in imaging are:

- 1) Acquire image data
- 2) Reconstruct images
- 3) Utilize images (diagnosis/research)

1) Acquire image data: Data obtained (on computer) as either raw data detector output (RAW) or sinograms (formatted about which can easily specific histograms of detected events. In a sinogram, many detected events can

2) Reconstruct images: Images can be reconstructed using analytic or iterative reconstruction. The advantage from an analytic reconstruction, is that images can be rendered and displayed in many useful ways.

3) Utilize images (diagnosis/research): Reconstructed 3D images can be rendered and displayed in many useful ways.

3D views, MP images, 3D

ANALYTIC VS ITERATIVE RECONSTRUCTION

There are two main types of mathematical algorithms for image reconstruction: analytic reconstruction (Filtered Back Projection) and iterative reconstruction.

- Analytic reconstruction: on the whole we focus on an image reconstruction technique called Filtered Back Projection (FBP). The mathematics of FBP are based on the central slice theorem (2D/3D), but are not discussed here.
- Iterative reconstruction: these algorithms involve a feedback process that permits periodic adjustments of an estimated image so that its virtual acquisition corresponds to the raw acquisition. They run by repeating (iteratively) the Back Projection. (1) Reconstructed projections are subtracted by forward projecting data (using system matrix), and is based on a validity distribution estimation from the previous iteration, and (2) the current image estimate is compared to the raw acquisition and updated so as to minimize the likelihood it is the "correct" image estimation.

FBP has been the reconstruction algorithm traditionally used for medical imaging. It is much faster, simpler, reproducible, and linear (performs uniformly across environments). Non that simulating scatter is getting more accurate, many vendors are incorporating iterative reconstruction techniques into their systems. While iterative reconstruction is more complex, it has advantages in that it is capable of dealing with noise and other practical issues by incorporating their associated uncertainties into the reconstruction process.

This website shows animations of FBP reconstruction.

FILTERED BACK PROJECTION (FBP)

The main steps involved in a Filtered Back Projection image acquisition include:

- (1) Forward projection (Data acquired and forward projected into the sinogram space)
- (2) Data is filtered (the filter in Filtered Back Projection)
- (3) Filtered sinograms are back projected into image space (the back project in Filtered Back Projection)

IMAGE ACQUISITION (FORWARD PROJECTION) CT, SPECT

(In) Emission volume Sinogram (stored data)

Intensity profile

Forward Projection

angle 0°

Rho (offset)

In CT and SPECT imaging, a sinogram is generated by rotating detectors around a patient, and along the selected projection profiles at each angle in the sinogram, as detailed in the gif above. This gif essentially illustrates a SPECT acquisition, where the information about the distribution of a radioactive tracer is being emitted from within the patient (through patient absorption) and usually registered by the rotating detectors (an emission scan). A CT scan would work very similarly, with respect to image acquisition and reconstruction, except the photons reaching the detector would be coming from an x-ray generating source at the other side of the patient (a transmission scan).

Of course we can read that a CT scan, a transmission scan, would give us information about the attenuation properties of the object being imaged - thus providing anatomical information. In contrast a SPECT scan, which is an emission scan, would tell us where a pharmaceutical is distributing throughout the body - thus providing functional information.

PET TOMOGRAPHY

For a PET acquisition, a patient is placed within a ring of detectors. Unlike SPECT, there are no rotating cameras or beds. However, sinograms are created much the same way. Virtual (sinogram) profiles per angle can be generated by imaging and sorting the detector pair events (based on a system matrix provided by machine manufacturer). The below gif is provided to help visualize the lines of response and how they relate to the sinogram.

Lines of response between PET detectors

Corresponding location in sinogram

Theta (angle)

Rho (offset)

PET ACQUISITION

PET images are generated through detection of the 511 KeV photons that arise during positron annihilation. The process of a positron combining with an electron, resulting in a transformation of particles with mass, to (massless) photons with energy. Data is collected by setting each event into its approximate location in sinogram space - each line of response has a corresponding angle and offset to indicate its location in the sinogram.

Emission volume + PET detectors Sinogram (histogram)

Theta (angle)

Rho (offset)

Events processed: 1

The FBP of emission tomography when acquisition events taking place with a PET detector ring. As events are detected, they are recorded in the scan's sinogram. Only certain events are illustrated, as the total data would not be too numerous to display.

IMAGE RECONSTRUCTION (BACKPROJECTION AND FILTERED BACK PROJECTION)

Once a sinogram is created (and stored in a computer), we can then use it to reconstruct a 3D image.

BACK PROJECTION (without filtering)

Back projection is a process in which we "smear" the measured profile associated with each specific angle of acquisition, across the image space. Back projection profiles in the sinogram (originally created and stored in sinogram of image acquisition), can be backprojected at the angle it was acquired at. The emission scan illustrates four information stored at each angle in the sinogram is backprojected into image space.

Image space Sinogram

Theta (angle)

Rho (offset)

Back Projection Principle (with no filter)

The above animation illustrates how sinogram data is smeared into image space backprojected. When we are reconstructing an image, we backproject more than a single angle of data - essentially we backproject all the angles, and add their backprojected images together in image space. The emission data shows four multiple angles in the sinogram can be backprojected together to create a backprojected image.

Reconstructed image Sinogram

Theta (angle)

Rho (offset)

Back Projection

The blurring which takes place during back projection is referred to as "in-blurring".

FILTERING

Back projection does not work as a useful image reconstruction method because of the blurring mentioned above. This blurring however can be corrected if we find filter the data. It usually requires some filter can be applied very easily, as it is simply a multiplication function in the frequency domain (data can be transformed easily using the Fourier transform). In imaging, often we are working with discrete digital data, so we use the "Fast Fourier Transform" (less numerical ranges in 2D) for speed and accurate transformation of data to and from frequency space, thus allowing for very fast processing.

Sinogram Profile, angle = 0

Theta (angle)

Rho (offset)

Sinogram Ramp Filtering

Percent backprojected 5% from selected angles

Several different types of filters can be used, but the basic most used filter is called a ramp filter, which compensates for the 1/r blurring effect that manifests during back projection. The negative of using the ramp filter alone is that it amplifies high frequency noise. This could not be a problem if our images were measured, but that is not the case in medical imaging. Other filters, which attenuate the ramp filter, can be used to attenuate the amplification of high frequency noise. (Iterative reconstruction methods also use filters for optimizing accuracy).

FILTERING THEN BACKPROJECTION

Once sinograms are filtered, they can be back projected to recover an accurate representation of the original subject.

Reconstructed image Filtered Sinogram

Theta (angle)

Rho (offset)

Filtered Back Projection

FILTERED BACK PROJECTION

The process of filtering sinogram data and then back projecting it is called Filtered Back Projection reconstruction.

We can reduce that to actually reconstruct an image, we need to back project information from all 180 degrees of acquisition data. This can be exemplified with the following gif, in which images are created using any subsets of the data (left into angles).

Reconstructed image Sinogram

Theta (angle)

Rho (offset)

Filtered Back Projection

Percent backprojected 5% from selected angles

And

Reconstructed image Sinogram

Theta (angle)

Rho (offset)

degrees of acquisition data. This can be exemplified with the following gif, in which images are created using any subsets of the data (left into angles).

Reconstructed image Sinogram

Theta (angle)

Rho (offset)

Filtered Back Projection

Reconstructed image Sinogram

Theta (angle)

Rho (offset)

Filtered Back Projection

SUMMARY

This website the four of animations I made to help understand image reconstruction.

Iterative medical animation can be downloaded:

[PET](#) [CT](#) [Phantom](#) [Noise](#)

December 2014 - generate gifs with your own images!

Download gifmaking essential file (zip)

COMPUTER REQUIREMENTS: Recon-3D/Filter3D/3D can be an executable built in the C/C++ programming language. The run, need regular multi-line IDE or the (free) IDE: virtual machine installed. (IDE: www.jetbrains.com/).

INSTRUCTIONS - Details about the Recon-3D/Filter3D/3D can be found in the user manual. The program will not be built in a 32-bit and image saved in jpg format. Site will then be generated based on user supplied jpg processing may require 1-2 minutes (user should see animation frames being created)

OUTPUT - gifs will be created in an subject folder placed at the location of the image

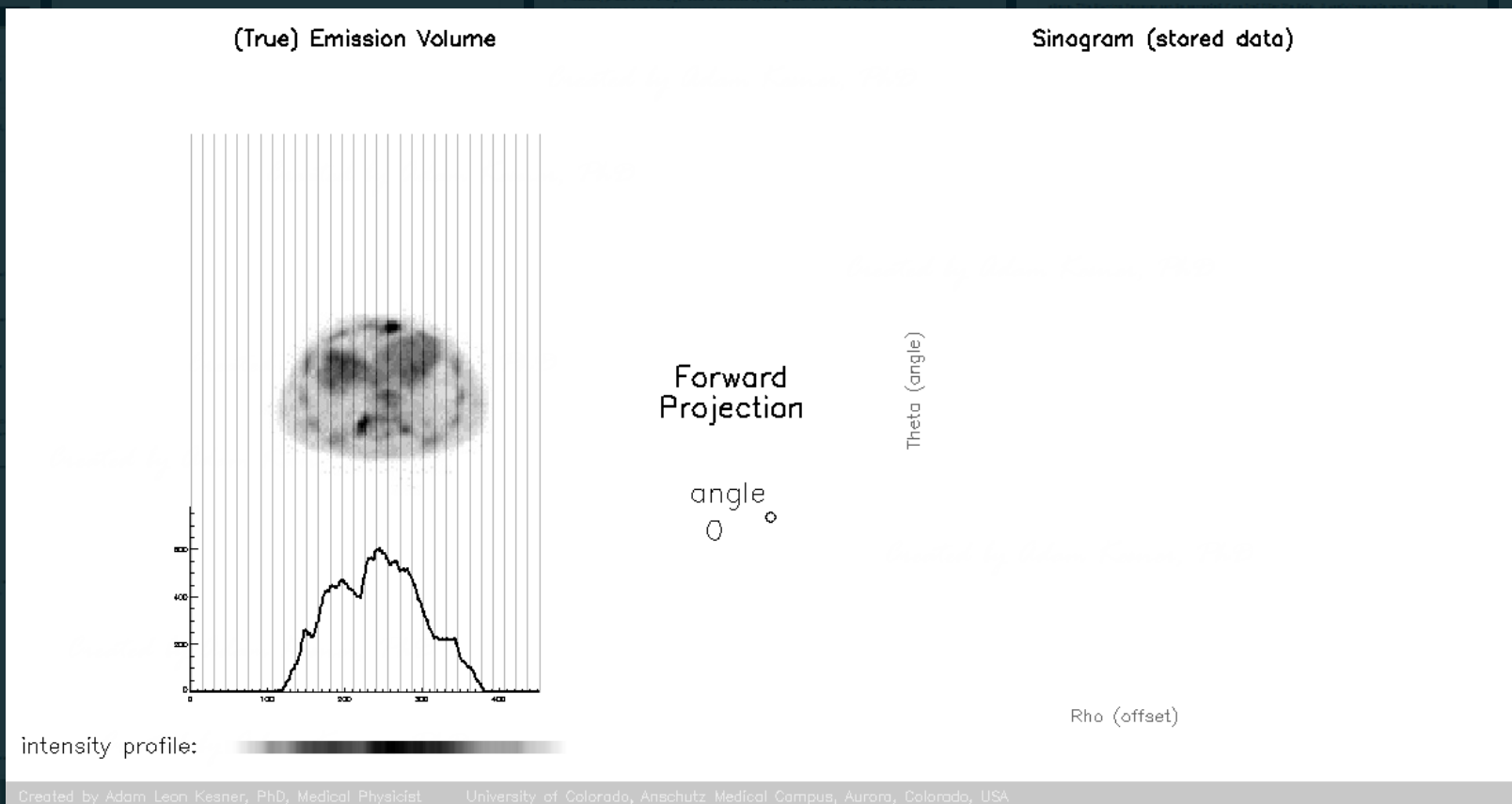
Any comments/suggestions for the page are welcome: adam@adamquidmore.edu

© Adam Quidmore - Head of the University Physicians, The Denver Children's Hospital, and a Researcher in the Department of Pediatrics, University of Colorado Denver, Aurora, Colorado

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3D image reconstruction explained with gifs

University of Colorado Website
Google:
image reconstruction animation

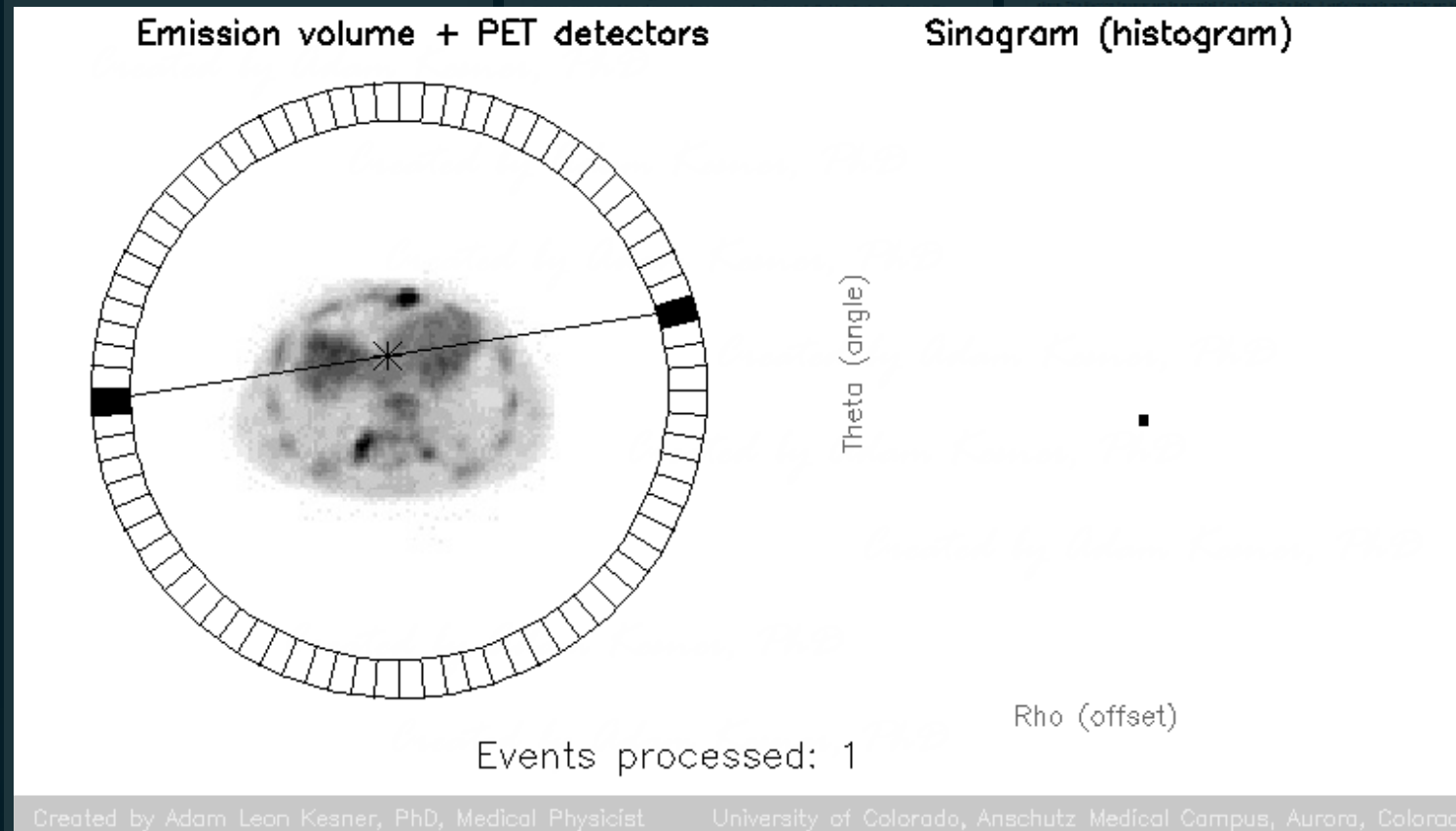


Created by Adam Leon Kesner, PhD, Medical Physicist University of Colorado, Anschutz Medical Campus, Aurora, Colorado, USA

gif example 1/3

3D image reconstruction explained with gifs

University of Colorado Website
Google:
image reconstruction animation

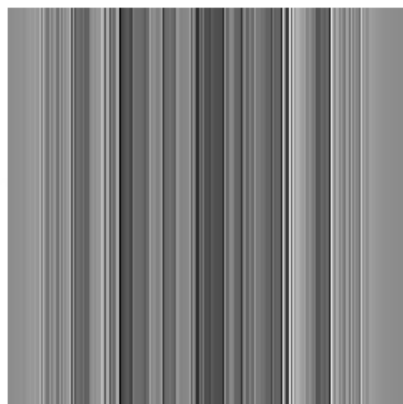


gif example 2/3

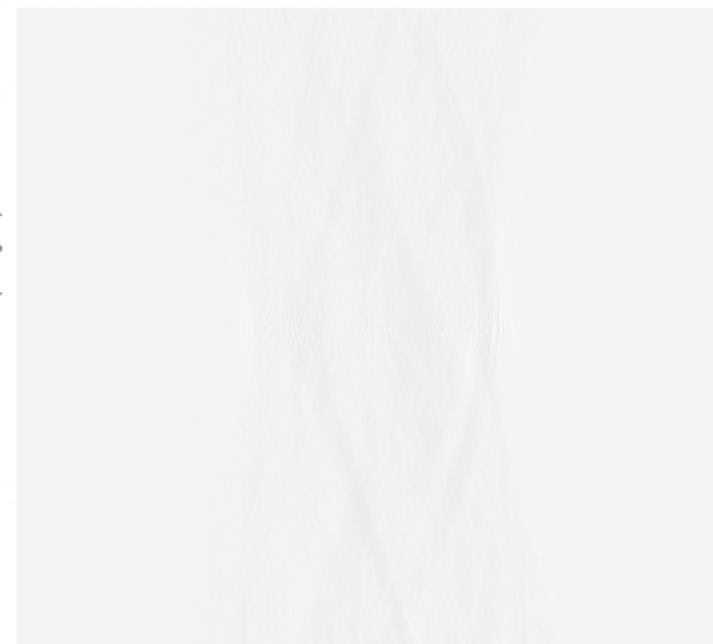
3D image reconstruction explained with gifs

University of Colorado Website
Google:
image reconstruction animation

Reconstructed image



Filtered Sinogram



← Filtered Back Projection

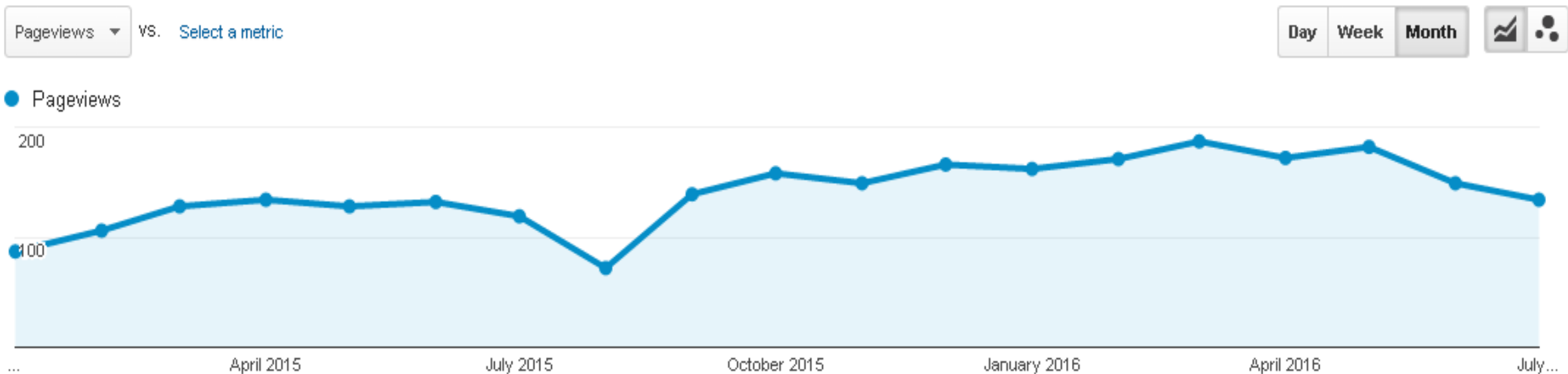
Created by Adam Leon Kesner, PhD, Medical Physicist University of Colorado, Anschutz Medical Campus, Aurora, Colorado, USA

Website

- Tutorial text and animations have been posted online
 - Simple web page format
- Freely available to view or download
 - Global access
- Animations presented with focus on nuclear medicine/PET
 - Emission, transmission (CT) animations are also available
- Mirror website hosted on the IAEA Human Health Campus

Website access

- Top google hit for “image reconstruction animations”
- Accessed from 50+ countries

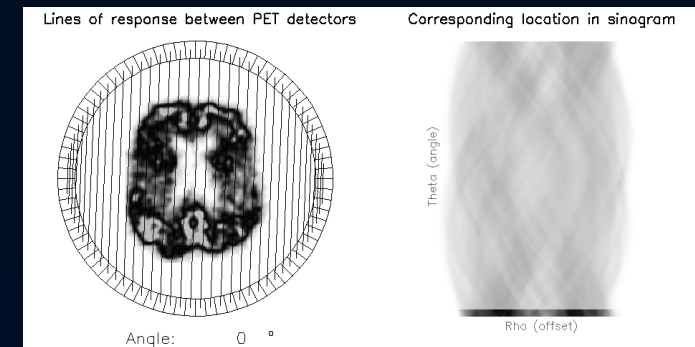
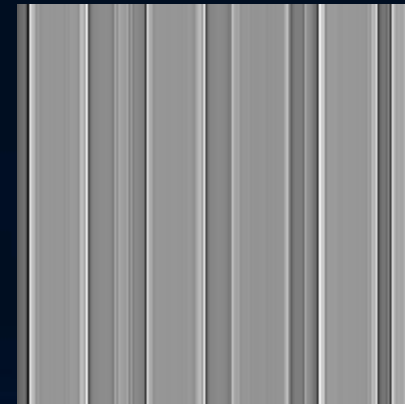
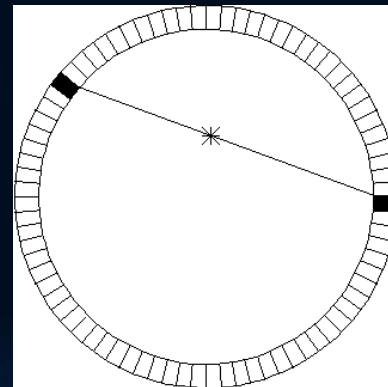
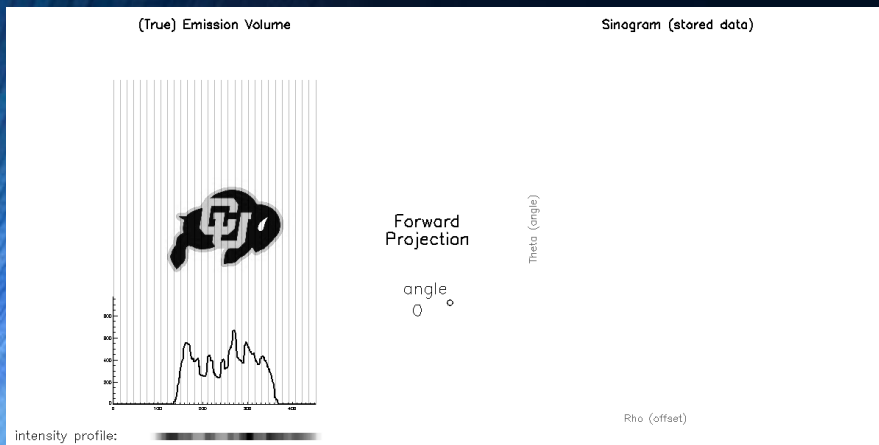


2016 - Interactive tool added to site

- December 2015 – interactive tool added to allow users to create their own reconstruction animations
- Written in IDL, can be run with free virtual machine



Recon gif maker 3000



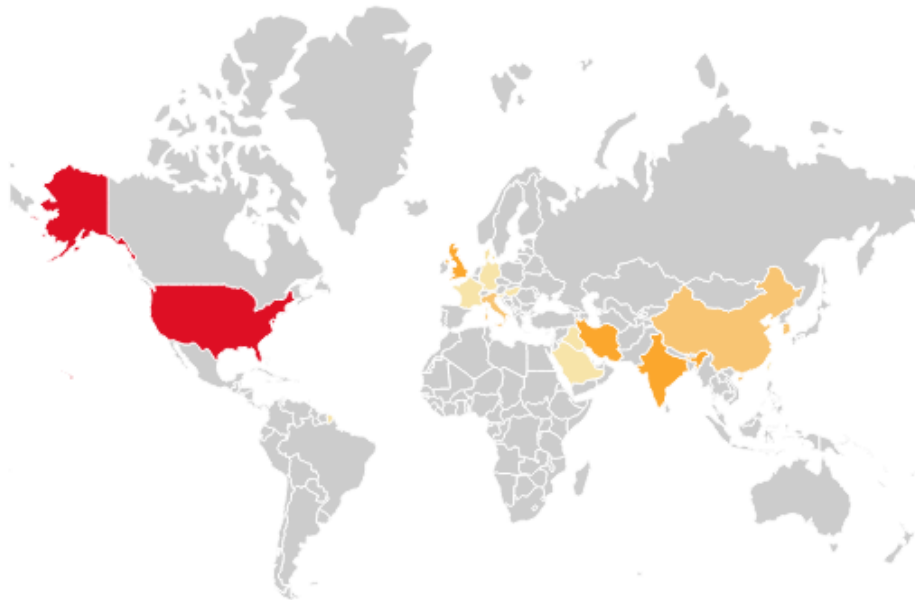
Interactive tool

- Downloaded approximately 60 times



Recon gif maker 3000

GEOGRAPHIC DISTRIBUTION OF CLICKS



Top Countries (clicks / % of total)

United States	23	49%
United Kingdom	4	9%
India	3	6%
Iran, Islamic Repu...	3	6%
Korea, Republic of	2	4%
Italy	2	4%
China	2	4%
France	1	2%
Denmark	1	2%
Saudi Arabia	1	2%
Slovenia	1	2%
Hungary	1	2%
Taiwan	1	2%
Iraq	1	2%
Germany	1	2%

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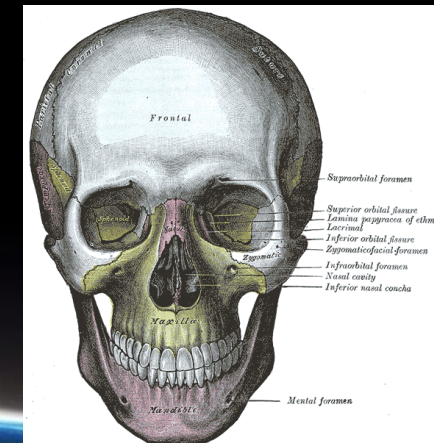
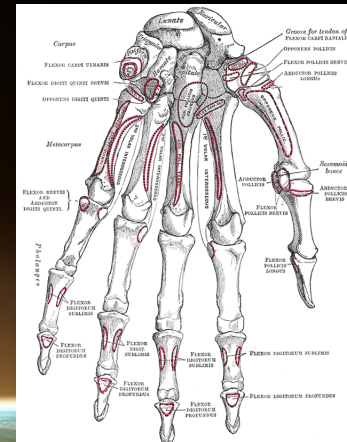
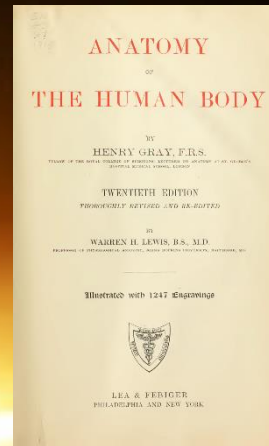
Summary

- Identified a need for improved teaching tools to help visualize the (temporally variant) concepts of image reconstruction
- gif animations can be a useful tool for this aspect of education
 - Robust file format
- Disseminating material freely on the web appears to be a good way to maximize their impact in the community
 - Images can be downloaded and included in powerpoint lectures
- Positive feedback has been collected from users
- Practical way to move modern medical physics education beyond textbooks
- Increase visibility of medical physics/medical physics educational innovation in the community

Future directions

- Grant money to support:
 - Full animated reconstruction course (including iterative reconstruction)

1858
Henry Grey



- Maybe it's time for 21st century animated medical physics standard book